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Coal Mine Air Tempering: Effectiveness, Design, and Roof Support

By Gary P. Sames

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F	degree Fahrenheit	mi	mile
ft	foot	min	minute
fpm	foot per minute	pct	percent
in	inch	yr	year
in Hg	inch of mercury (atmospheric pressure)		

COAL MINE AIR TEMPERING: EFFECTIVENESS, DESIGN, AND ROOF SUPPORT

By Gary P. Sames [1]

ABSTRACT

Shale roof deterioration in coal mines, caused by ventilation air humidity fluctuations, is a common ground control problem. Shale roof deterioration often results in increased accidents, decreased production, inadequate ventilation, and increasing operating costs in maintaining haulage roads and airways. The results of Bureau of Mines research indicate that air tempering entries are an effective method of controlling deterioration prone shales.

Some of the conclusions and recommendations drawn from Bureau research include (1) moisture sensitive shales will react adversely to moisture gains and losses, (2) the majority effect of specific humidity fluctuations can be concentrated in and absorbed by tempering entries, (3) tempering entry panels should be located as near to the main intake as possible, (4) tempering panels should be designed for a conservative recovery and provide a minimum of 20- to 30-min air residence time, (5) ventilation and escapeway requirements must be considered early in panel design, and (6) an efficient support and sealant plan can increase the life expectancy of a tempering panel.

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INTRODUCTION

The effects of humid mine air on moisture sensitive shales are well known and documented (1-6).[2] Shale roof deterioration results in a progressive loosening and spalling upwards of roof material until an unaffected rock unit is reached. This action usually defeats the purpose of any installed support, leaving bolts hanging free from the roof, and posts standing under columns of shale as spalling continues between them.

Shale roof deterioration due to atmospheric moisture has been recognized in many coalbeds, but is especially severe in the Pittsburgh Coalbed in the Dunkard Basin and the Harrisburg (No. 5) Coalbed in the Illinois Basin. In these coalbeds, shale deterioration often results in roof fall accidents, decreased production, inadequate ventilation (because of obstructed airways), and increased costs in maintaining haulage roads and airways (7).

Techniques developed to control shale roof deterioration include leaving top coal, applying sealants, water sprays, and air tempering. Each, however, has its own drawbacks, and none have gained wide industry acceptance.

The practice of leaving the top 4 to 6 in of coal and bolting it to the roof is the most widely used method of protecting sensitive shales from humid mine air. This method works well for a time when the coal adheres strongly to the roof, but it will eventually sag, separate from the roof, and fall. Top coal also requires careful mining to avoid cutting into the roof and exposing the shale. Regardless of the care taken, mistakes and unavoidable geologic discontinuities (clay veins, roof and floor rolls, washouts, coal thinning) encountered during mining will result in areas of exposed shale roof.

A coating of gunite, shotcrete, coal tar, or a polymeric sealant on the shale surface is very effective in controlling deterioration (8-10). However, the widespread use of these products in mines is limited by their high cost. It is often feasible to apply a sealant to only the most critical areas of a mine to be maintained.

An early method of controlling humidity fluctuations was to pass the intake air through a series of fine water sprays (11-12). Water sprays cooled and maintained high intake air moisture levels during summer months, and warmed and increased intake moisture levels during winter months. This method proved effective in creating stable high-humidity intake air, but became uneconomical with winter freezes, rising costs, and increasing ventilation requirements.

A method of stabilizing air moisture content before coursing it throughout the mine that has gained some support in industry, and the interest of the Bureau of Mines, is air tempering (7, 13). Air tempering stabilizes intake air humidity by first coursing it through old workings or a series of entries especially designed and supported for that purpose. Air velocity through the tempering entries is greatly reduced, thereby increasing the time it is in contact with the surrounding rock, allowing it to reach mine temperature and humidity. The air is then directed to working areas of the mine where interaction between it and moisture sensitive shale roof is minimized. Air tempering is a promising control measure for shale roof deterioration because of its simplicity, relatively low cost, and ease of incorporation into most existing mine layouts.

The primary objectives of this Bureau investigation were (1) to evaluate the effectiveness of air tempering in maintaining safer, more productive conditions under moisture sensitive shale roof, and (2) identify, discuss, and evaluate available guidelines for tempering entry design and support.

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[2] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

BACKGROUND

This study is a followup investigation designed to update and consolidate information collected during this and previous Bureau contract research into the interactions between mine air moisture content and mine roof stability (2, 5, 7).

Aughenbaugh (2), through several field studies conducted primarily in the Illinois Coal Basin, concluded the following: seasonal humidity changes are reflected in the mine air, intake air undergoes rapid tempering along its course, and there are seasonal moisture interchanges between mine rock and air. Aughenbaugh also determined in laboratory studies that neither temperature nor barometric pressure have direct influence on shale durability, and that the rate and depth of moisture absorption into a shale is controlled by bedding planes, fractures, and holes interrupting the exposed surface.

Haynes (5), in field and laboratory studies conducted in the Warrior Coal Basin in Alabama, reported the following: a high degree of correlation between strain developed in samples of roof rock and humidity changes, strain developed across bedding planes was greater than strain developed parallel to bedding, and that roof rock specimens reacted to a 10 pct change in humidity throughout a 7- to 10-day period before stabilizing.

Cummings (7) presented the results of a field investigation and laboratory studies in the Dunkard Coal Basin in West Virginia (in a now abandoned section of the same mine examined in this study). Cummings found that the claystone strata above the Pittsburgh Coalbed does absorb moisture at high humidities and release it at low humidities, but while the moisture absorption capabilities of the claystone does not greatly exceed those of other roof rocks, it has a markedly greater tendency to expand. Cummings also concluded the following: measurements of the mine atmosphere can establish the nature and extent of annual humidity fluctuations and show the distribution of moisture along the aircourse, excess moisture during high summer humidity is absorbed by the mine rocks, cyclic humidities produce increasing moisture susceptibility in claystone, and the most beneficial effects of air tempering are experienced within 30-min air residence time.

The wide geographic distribution of Bureau studies into the interaction between mine roof stability and air moisture content, and the similarity and continuity of the results obtained, suggest that mine roof response to changing weather conditions is a phenomenon common in coalbeds east of the Mississippi River. The degree to which various roof shales react to humidity fluctuations is dependent on the nature of the shale, not on its geographic location. Similar roof shale types occurring in differing localities can be expected to react similarly to changing mine air moisture conditions. Therefore, the data and information detailed in this report are generally applicable to similar mining situations, and the conclusions and recommendations are generic in nature. Similar intake air moisture gain and loss characteristics as a function of mine air residence can be expected in coal mines in the above areas, with differing degrees of roof deterioration dependent on shale type susceptibility.

ACKNOWLEDGMENTS

The author gratefully acknowledges Valley Camp Coal Co.'s full cooperation in this study, and the No. 1 Mine's management team for providing assistance and mine personnel for underground visits.

MINE GEOLOGY

Field work during this investigation was conducted at the Valley Camp Coal Co. No. 1 Mine near the town of Triadelphia in the northern panhandle of West

Virginia. The No. 1 Mine is one of only a few mines operating in the United States with fully operational tempering entries integrated into their mine designs. The mine is located near the northeast trending axis of the Dunkard Basin, and is operated in the Pittsburgh Coalbed (fig. 1). The topography above the mine is hilly, with steep-walled, narrow, V-shaped stream valleys. Maximum topographic relief is approximately 400 ft in the study area, and overburden thickness ranges from 400 to over 800 ft.

Throughout most of the mine, the Pittsburgh Coalbed averages 5 ft in thickness and is overlain by a clay parting, rider coal, and shale with coal stringers that varies from 0 to 5 ft combined thickness. Above this occurs the moisture sensitive unit, a severely slickensided gray-green claystone 3 to 7 ft thick. Above the claystone the main roof consists of highly argillaceous, sometime nodular, microcrystalline limestones (fig. 2*A*). The limestones are unaffected by humid air and represent the upper limit of roof deterioration.

In some areas of the No. 1 Mine the normal sequence of clay parting, rider

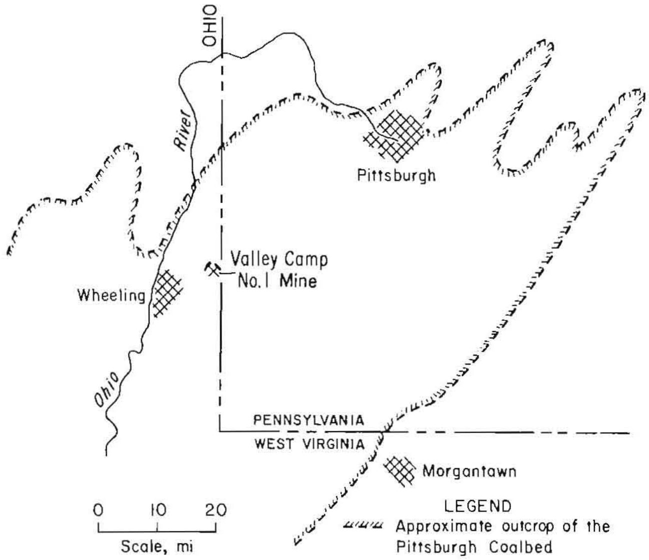

FIGURE 1. - Location map showing Valley Camp No. 1 Mine and general trend of the Dunkard Basin by the outcrop of the Pittsburgh Coalbed.

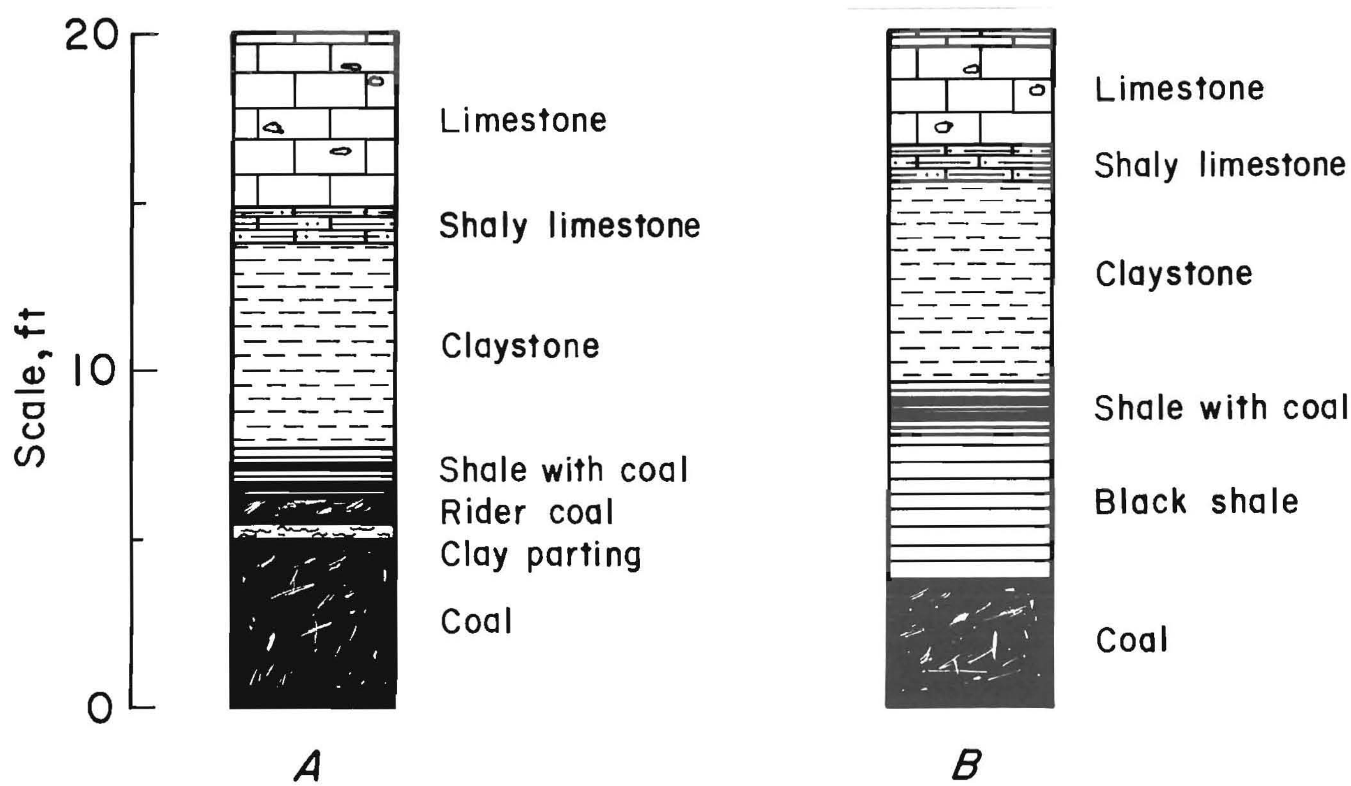

FIGURE 2. - Generalized stratigraphic columns of Pittsburgh Coalbed and its associated roof rock in the No. 1 Mine. *A*, Normal sequence of immediate and main roof rock types; *B*, immediate and main roof rock sequence in the 3 South area.

coal, and shale with coal stringers is absent above the Pittsburgh Coalbed. In their place occurs a hard, slightly jointed, moderately fissile, black organic shale that is 3 to 6 ft thick. The Pittsburgh Coalbed thins to 3 to 4 ft under areas of the anomalous black shale roof. Above the black shale is 1 to 2 ft of shale with coal stringers and the normal occurrence of 3 to 7 ft of gray-green claystone and then the limestone main roof (fig. 2*B*).

SHALE DETERIORATION

Shales are the most common material forming coal mine roof rock. Shale is a fine-grained sedimentary rock composed mainly of silt and clay particles. It is the result of the lithification (compaction and cementation) of clay and mud deposits that are formed in many different environments. The depositional environments in the ancient coal swamps that formed today's coalbeds produced a wide variety of shales, including organic black shales, gray, gray-green, and blue shales, siltstones, mudstones, claystones, and fireclays. Roof shales can range from beds with clay particles that are in parallel orientation, creating high fissility (ability to be split into thin layers); to beds of randomly oriented clay particles, creating poor fissility, slickensides, and cracks; to massive, well cemented beds.

Shales are susceptible to moisture changes to differing degrees. In the underground mine environment where surface weather changes are reflected in the mine atmosphere, humidity may have a direct influence on shale roof stability. Various studies have shown by laboratory and in situ measurements that shales do respond to various humidity conditions by absorbing or giving up moisture (1-2, 5, 7, 12, 14-15). The effects of humid mine air on roof shales include (1) an interaction with the mine air to either gain or lose moisture to a natural equilibrium point, (2) an expansion or contraction of the shale with respect to moisture gains or losses, (3) a weakening of the shale because of changes in moisture content, and (4) the development of excess stresses in the confined state (solid roof rock mass) because of restriction in volume expansion (1).

There are no generally accepted methods for premining determination of shale susceptibility to moisture induced deterioration. Tests sometimes used to assess shale moisture susceptibilty include degree of sample slaking when immersed in water, measurement of sample swelling and weight gains when exposed to 100 pct relative humidity atmospheric conditions (7), and observation of samples exposed to natural weathering conditions. Examination of cored roof rock can also give clues to its degree of susceptibilty. Very fine grained claytones, mudstones, and poorly cemented shales should be suspect. Hard, well cemented shales and siltstones may be expected to be moisture resistant. Sample examination coupled with water immersion or extended exposure to weather gives a good indication of roof rock deterioration susceptibility, but cannot be considered definitive. Close attention to roof conditions during early development provides the best indicator.

The two shales of primary concern in this study are the black shale of medium to low fissility, and the highly slickensided, poorly fissile gray-green claystone.

The black shale roof in the No. 1 Mine has a high quartz content and is a very well cemented unit showing little susceptibility to moisture absorption. Excess moisture in the air in areas of black shale roof is not readily absorbed by the shale, but can be seen as beads of condensate on the shale surface.

The claystone shale roof is a very soft, poorly cemented unit that consists almost exclusively of clay sized particles. The claystone appears to be overcompacted, with innumerous small, randomly oriented slickenside surfaces and small cracks, and displays a definite affinity for moisture absorption and swelling. As wet and dry cycles occur, successive layers of the claystone are exposed to and affected by swelling as previously weakened layers slough from the roof.

AIR TEMPERING

PURPOSE

Air tempering has the effect of evening air temperature throughout the year. However, while temperature changes on the scale common in most mines have been found to have little or no effect on mine roof rocks, even small changes in temperature can have a great effect on relative humidity values (5, 14). In order to observe the effects of actual moisture changes on mine roof stability, it is necessary to first eliminate the relative effect of temperature on humidity measurements. Specific humidity, measured by weight of water vapor per unit weight of dry air, is used in this study to illustrate mine air moisture changes that occur in tempering entries.

Tempering entries are primarily designed to alleviate the effects of warm, wet (high temperature and high specific humidity) summer intake air on roof conditions through condensation and absorption. However, tempering entries affect the moisture content in every season, resulting in a reduction in the magnitude of specific humidity fluctuations that would otherwise occur further inby as seasons change.

SEASONAL TRENDS

In the summer, as warm, humid air enters an open panel of cool tempering entries its velocity is greatly reduced, allowing it to interact with the surrounding rock and quickly reach mine temperature. As air temperature is reduced, its relative humidity will rise until the air is unable to carry the high moisture levels. Moisture at that point begins to condense on or be absorbed by the coal and rock, timbers, block, and rock dust in the entries. The intake air continues to cool and dry along the length of the entries until an equilibrium is reached between mine temperature and specific humidity levels.

In the fall months the average daily atmospheric temperature and specific humidity gradually drops. Tempering areas nearest the intake shaft begin to dry, losing the moisture gained during the summer months, and bringing the intake air to mine equilibrium. As the fall season continues, intake air is warmed and moisture released from the tempering entries further and further inby.

In the winter, cold average atmospheric temperatures reduce intake specific humidity to very low levels. The tempering entries become dry, then pass warmer dry air to the main intake entries. Significant drying may take place beyond the tempering entries throughout the winter, with very long residence times necessary for intake air to reach equilibrium.

During spring the increasing atmospheric temperatures warm the rock nearest the shaft, allowing the increasing specific humidity to be absorbed by the tempering entries. As spring continues a temperature and specific humidity distribution pattern very similar to summer's, but at lower overall values, is developed (fig. 3).

BENEFITS

Laboratory studies have shown that very short term (daily) fluctuations in specific humidity have little or no effect on shale moisture gains or losses (5, 7). Shales require a 7- to 10-day exposure to changes in specific humidity, whether higher or lower, before equilibrium between moisture content in the sample and atmospheric conditions is reached (5). However, very short-term air moisture fluctuations in mines are absorbed by tempering systems because of the large surface area in the entries (including rock dust, wood posts, and debris) and low air velocities. As the intake air travels along the entries, contact is made with rock and other materials in disequilibrium. Gradual moisture exchange takes place from that point at increasing residence times until equilibrium is again achieved (fig. 3).

Extended weather patterns, whether seasonal or because of stationary air masses (2 to 3 weeks), will sometimes affect the moisture content of the shale throughout the tempering entries. During extended

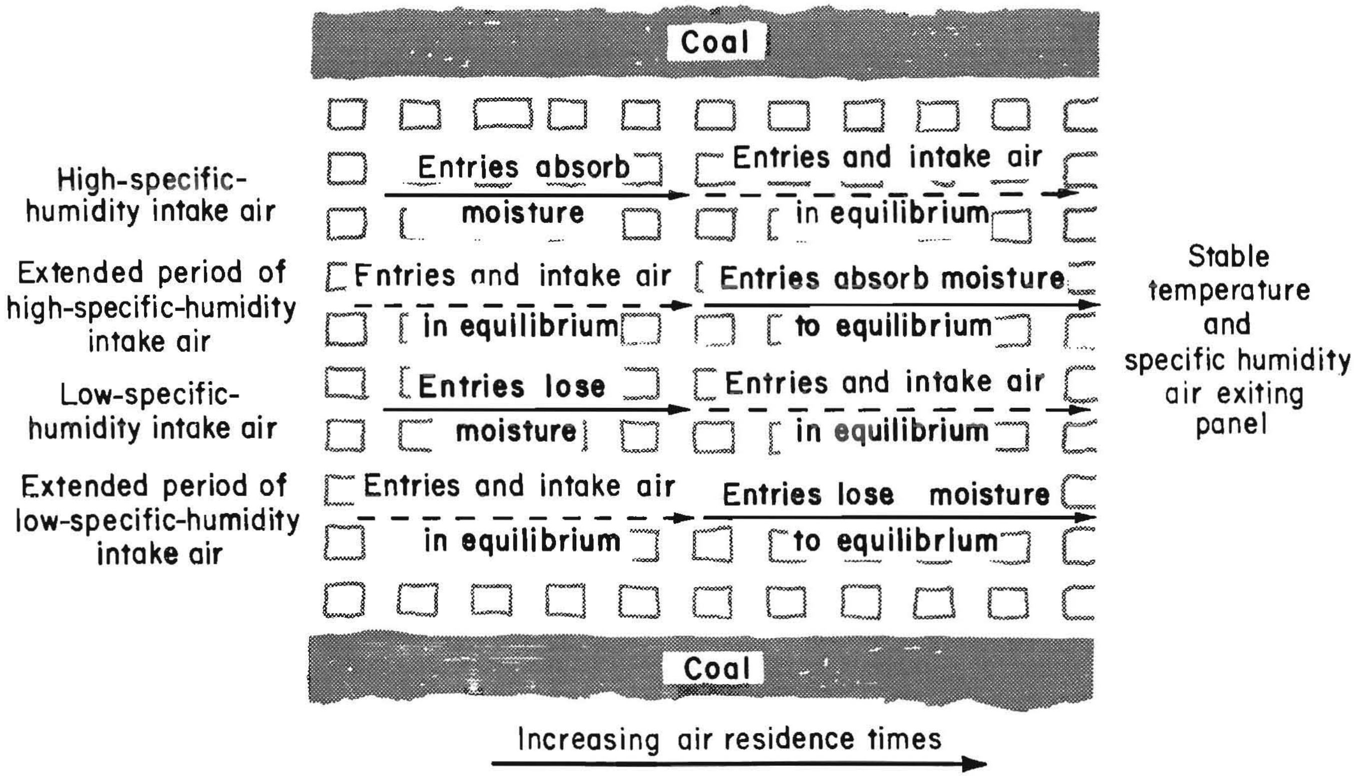

FIGURE 3. - Diagram of moisture gain and loss characteristics of a tempering panel experiencing various atmospheric conditions.

periods of either high- or low-specific-humidity intake air, the shale moisture content in the entire tempering system may reach equilibrium. When this happens, the entries are unable to either gain or lose additional moisture. The air exiting the tempering entries will then continue to temper in the main intake entries, and possibly working areas, depending on their distance inby.

Only when the entire area of the tempering entries is approaching or has reached equilibrium with intake air can the deleterious effects of atmospheric specific humidity fluctuations be transferred to active mining areas. Tempering entries react to specific humidity fluctuations, whether of moderate or seasonal duration, by concentrating and absorbing their effects.

NO. 1 MINE AIR TEMPERING SYSTEMS

EARLY SYSTEMS

The Valley Camp No. 1 Mine has used air tempering entries to control shale roof deterioration since early development. The No. 1 Mine's earliest tempering systems, including the abandoned 1 Right tempering entries, consisted of old workings (standard panels) with redesigned airflow patterns. After development of the panel to be used as tempering entries, the stoppings separating intake, return, and neutral air were removed to allow free movement and reduced velocity of the intake air in one direction. Roof support in the old systems was the same as the approved roof control plan for use in mining a standard production panel. In normal roof conditions the support consisted of 5/8-in-diam mechanical bolts 7 to 10 ft long on 4-ft centers, with only the escapeways posted. Top coal was left whenever possible, but because of the effects of humidity and inevitable sag it seldom lasted the full life of the entries.

CURRENT SYSTEM

The 3 South set of tempering entries now in use was especially designed, placed, mined, and supported for maximum life and efficiency. In 1979, 3 South became fully operational. It is located at the bottom of the Battle Run shaft, is 8 to 11 entries wide, and extends approximately 3,500 ft to the south (fig. 4). The mine roof at the bottom of the shaft is the hard black shale. The black shale is an oblong lens unit, long in the north-south direction, narrow east-west, and the coal thins under it from the normal 5 to 6 ft to 3 to 4 ft (fig. 4). The 3 South panel was mined in the center of the trend of the black shale lens to take advantage of its resistance to moisture deterioration.

The 3 South tempering entries were designed for an air residence time of 10 min with velocities of 300 fpm or less. Actual measured maximum air residence time in 3 South during this study was 15 min at an average velocity of 250 fpm.[3] Larger pillars were left in 3 South than in a normal production panel for increased roof stability (46 pct recovery versus 52 pct recovery in a normal production panel). Pillar height tapers from approximately 30 ft at the shaft to a normal 6 ft three splits inby. Approximately 2 to 3 ft of the black shale was mined with the coal along the remaining length of the panel to maintain the necessary clearance for personnel and machinery and to create the entry area necessary to maintain the low air velocities required in air tempering.

Roof support in 3 South is varied, tailored to the effects of differing air residence times along the length of the panel (fig. 5).

The first 500 ft of entry, or 1 to 3 min of air residence, is bolted with

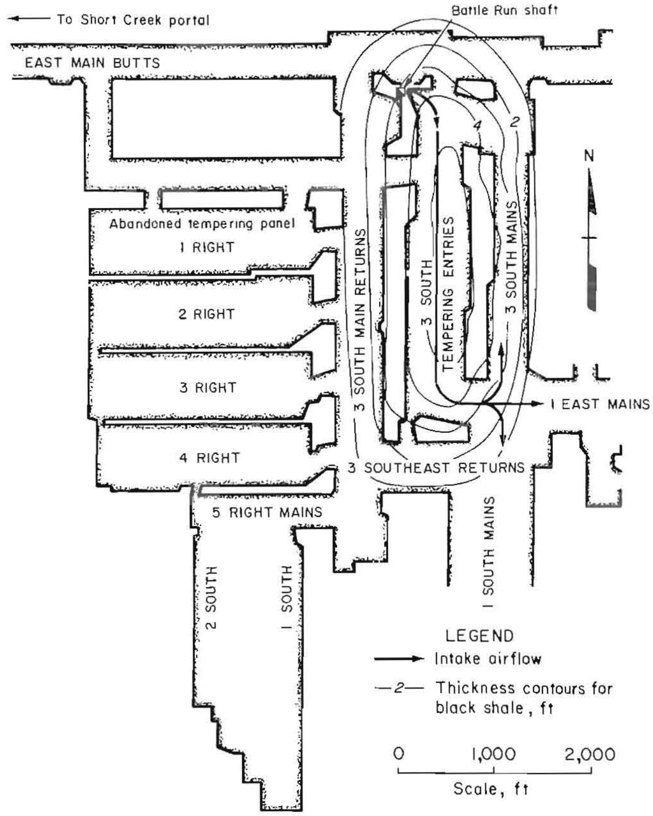

FIGURE 4. - General layout map of No. 1 Mine showing approximate thickness contours of anomolous black shale.

7-ft-long, 5/8-in-diam mechanical bolts on 4-ft centers with both rib and roof fully gunited. The gunite areas consist of a 1/2-in flashcoat of Mandoseal,[4] a layer of wire mesh, and a 1-1/2-in covering layer of shotcrete. The next 250 ft (2- to 4-min air residence) is also bolted with 7-ft mechanical bolts with both roof and rib sealed with a 1/2-in flashcoat of Mandoseal. These are the areas that are exposed to the most severe atmospheric conditions (greatest fluctuations) in the mine.

The remaining length of 3 South is supported with 5-ft full column resin bolts on 4-ft centers, two rows of posts on 5-ft centers in the main entries, and one row of posts on 5-ft centers in the crosscuts. The two westernmost entries were not posted because of production taking precedence over the tempering

[3]Production was halted for the duration of the study period because of prevailing economic conditions. The quantity of intake air was reduced during this time for cost savings; therefore, actual maximum air residence time during production will probably be lower (10 min) at a higher average velocity (300 fpm).

[4]References to specific products does not imply endorsement by the Bureau of Mines.

panel. However, no visible deleterious effects have occurred that can be attributed to lack of posts.

Most of the entries in 3 South are well rock dusted. Several of the original return entries have 5 to 6 in of rock dust spread on the floor. Concrete block stoppings were removed along the entire length of 3 South.

FIELD DATA

AIRFLOW SURVEYS

Standard airflow surveys using medium-speed anemometers were conducted in 3 South to determine the age distribution of the air in the entries. These data were plotted on the mine map and isolines of air residence were drawn to create a visual representation of airflow (fig. 6).

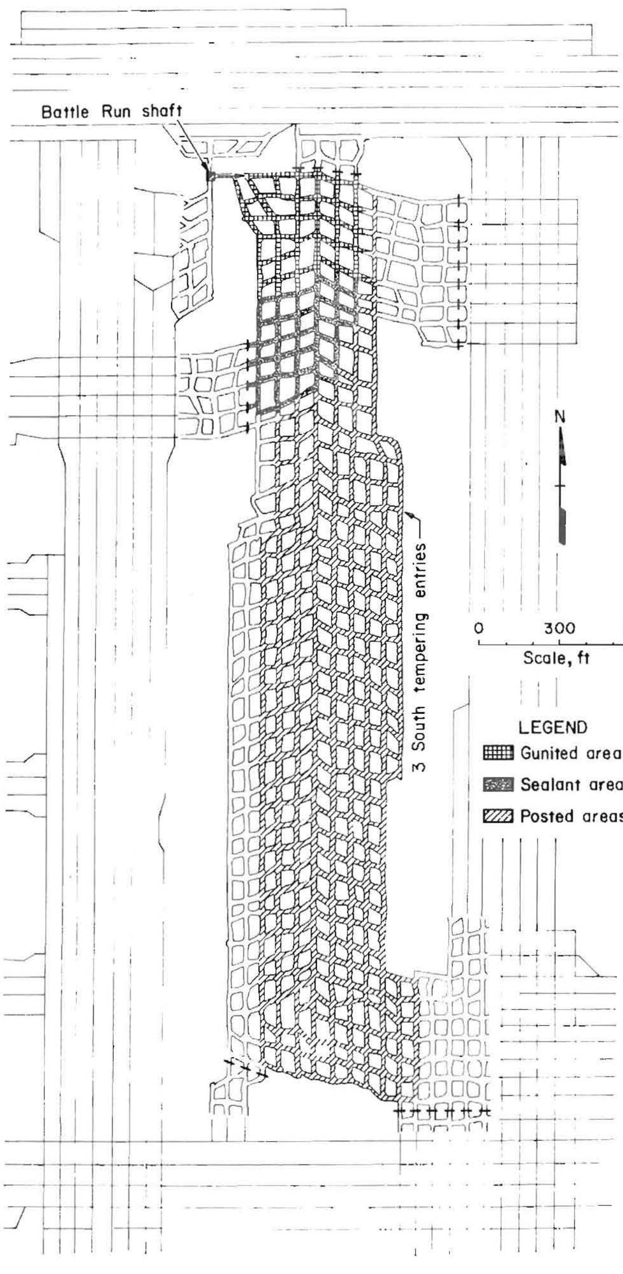

FIGURE 5. - Diagram of 3 South tempering panel outlining the installed roof support.

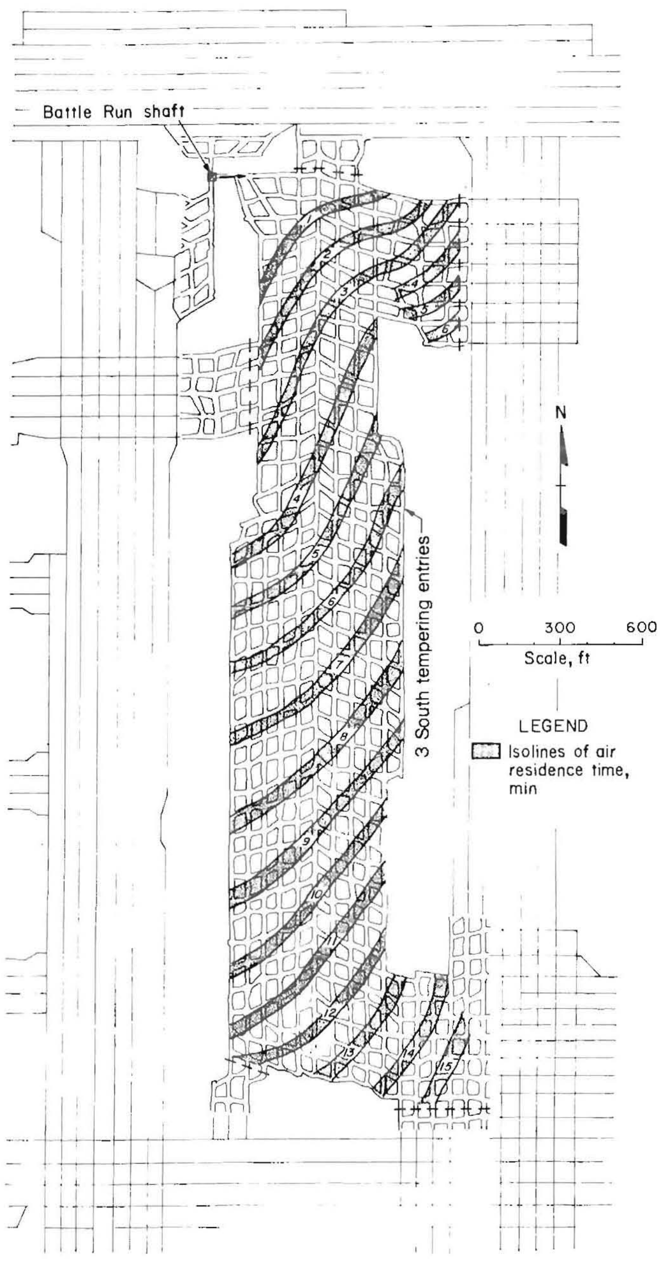

FIGURE 6. - Isoline map of air residence times in 3 South.

HUMIDITY SURVEYS

Humidity distribution was determined by wet-bulb, dry-bulb psychrometer checks at various stations throughout the 3 South entries. Humidity surveys were started in the early afternoon, after surface temperature and humidity conditions had stabilized. The humidity surveys were completed quickly to avoid the possibility of changing surface conditions affecting the data.

Data collected underground were converted to specific humidity for plotting on humidity distribution curves. Specific humidity is expressed as grains of moisture per pound of dry air.

TABLE 1. - Saturation vapor pressure table for given wet-bulb temperature values

Tw,[1] °F	Ps',[2] in Hg	Tw,[1] °F	Ps',[2] in Hg	Tw,[1] °F	Ps',[2] in Hg
20..	0.1027	40..	0.2477	60..	0.5216
21..	.1078	41..	.2575	61..	.5405
22..	.1130	42..	.2676	62..	.5599
23..	.1186	43..	.2781	63..	.5800
24..	.1243	44..	.2890	64..	.6007
25..	.1303	45..	.3002	65..	.6221
26..	.1366	46..	.3119	66..	.6441
27..	.1431	47..	.3239	67..	.6668
28..	.1500	48..	.3363	68..	.6902
29..	.1571	49..	.3491	69..	.7143
30..	.1645	50..	.3624	70..	.7392
31..	.1723	51..	.3761	71..	.7648
32..	.1803	52..	.3903	72..	.7911
33..	.1878	53..	.4049	73..	.8183
34..	.1955	54..	.4200	74..	.8463
35..	.2034	55..	.4356	75..	.8750
36..	.2117	56..	.4518	76..	.9047
37..	.2202	57..	.4684	77..	.9352
38..	.2290	58..	.4856	78..	.9667
39..	.2382	59..	.5033	79..	.9990

[1]Wet-bulb temperature readings.

[2]Saturation vapor pressures in inches of mercury.

Source: Smithsonian Meteorological Tables, 6th rev. ed., prepared by R. J. List, 1951, pp. 354-364.

Barometric pressure, psychrometer readings, and saturation vapor pressure for given wet-bulb temperatures (from table 1) are necessary to calculate specific humidity. Conversion formulas are as follows:

$$Pv = Ps' - \frac{(Pb - Ps')(Td - Tw)}{2{,}800 - 1.3(Tw)}, \text{ in Hg},$$

where Pv = vapor pressure, in Hg,

Ps' = saturation pressure, in Hg,

Pb = barometric pressure, in Hg,

Td = dry-bulb temperature, °F,

and Tw = wet-bulb temperature, °F;

and

$$W = \frac{(0.622)(Pv)(7{,}000)}{Pb - Pv},$$

grains moisture per pound of dry air,

where W = specific humidity, grains moisture per pound of dry air,

Pv = vapor pressure, in Hg,

and Pb = barometric pressure, in Hg.

After conversion, the air residence at the data collection stations was determined using the isoline map. The specific humidity values were then plotted against their respective air residence times (fig. 7). Temperature readings were also plotted to illustrate the cooling and warming effects of the tempering entries on the intake air (fig. 8).

SPECIFIC HUMIDITY DISTRIBUTIONS

The data in figure 7 show the seasonal effects on intake air moisture content as well as the tempering effects of the entries. Previous Bureau research (7) indicates that the maximum efficient air residence time for tempering summer air is 30 min in No. 1 Mine, with excessive additional residence time necessary for

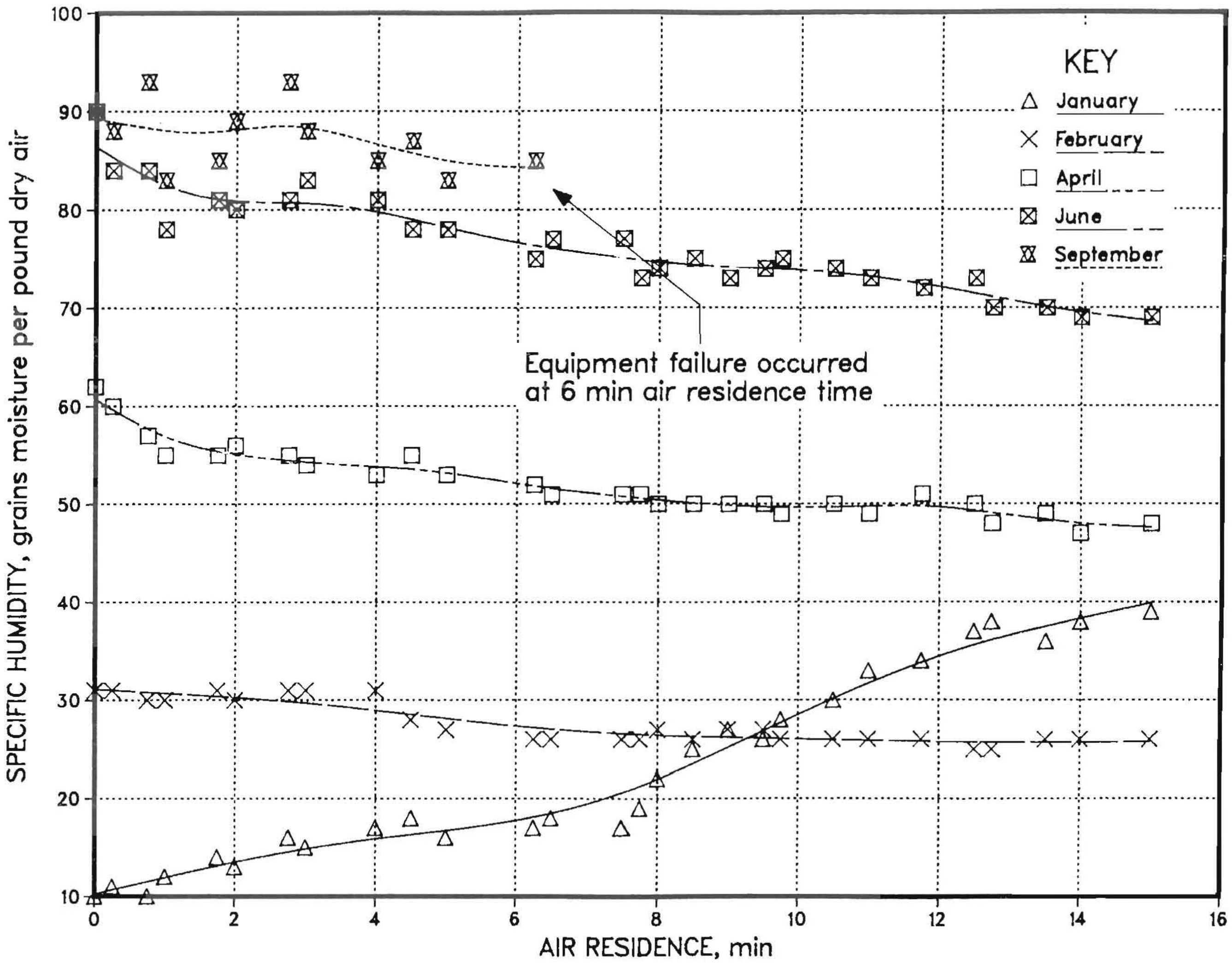

FIGURE 7. - Changes in mine air specific humidity as a function of air residence time.

total tempering. The same study estimates 60 grains per pound dry air as a good approximate summer moisture equilibrium value. Using 60 grains per pound as equilibrium, the summer curves in figure 7 indicate approximately a 70-pct reduction in excess air moisture above 60 grains in 15-min air residence. If summer air residence times approaching 30 min can be expected to achieve 90 to 95 pct tempering, then the additional 15 min account for only 20 to 25 pct of the total reduction of excess moisture to equilibrium.

The additional moisture loss in the remaining 15 min of residence time can be expected to occur in the main intake entries beyond 3 South (3 South Mains and 1 East Mains). Both mains reenter the claystone immediate roof and will probably experience moderate deterioration. The deterioration that occurs is due to the remining effect of the severest specific humidity fluctuations.

The curves for fall, winter, and spring in figure 7 follow the expected seasonal trends. Again, the tempering effects of the remaining 15 min of air residence time will occur in the 3 South and 1 East Mains intake entries. These effects should be very moderate (occupying the flattest portion of the distribution curves) when compared with those that occur in the 3 South tempering entries.

The effects of seasonal trends in specific humidity are not readily perceptible on the roof, rib, and floor surfaces themselves in 3 South. Instead, all of the materials used in mining and supporting the panel (wood posts, rock dust,

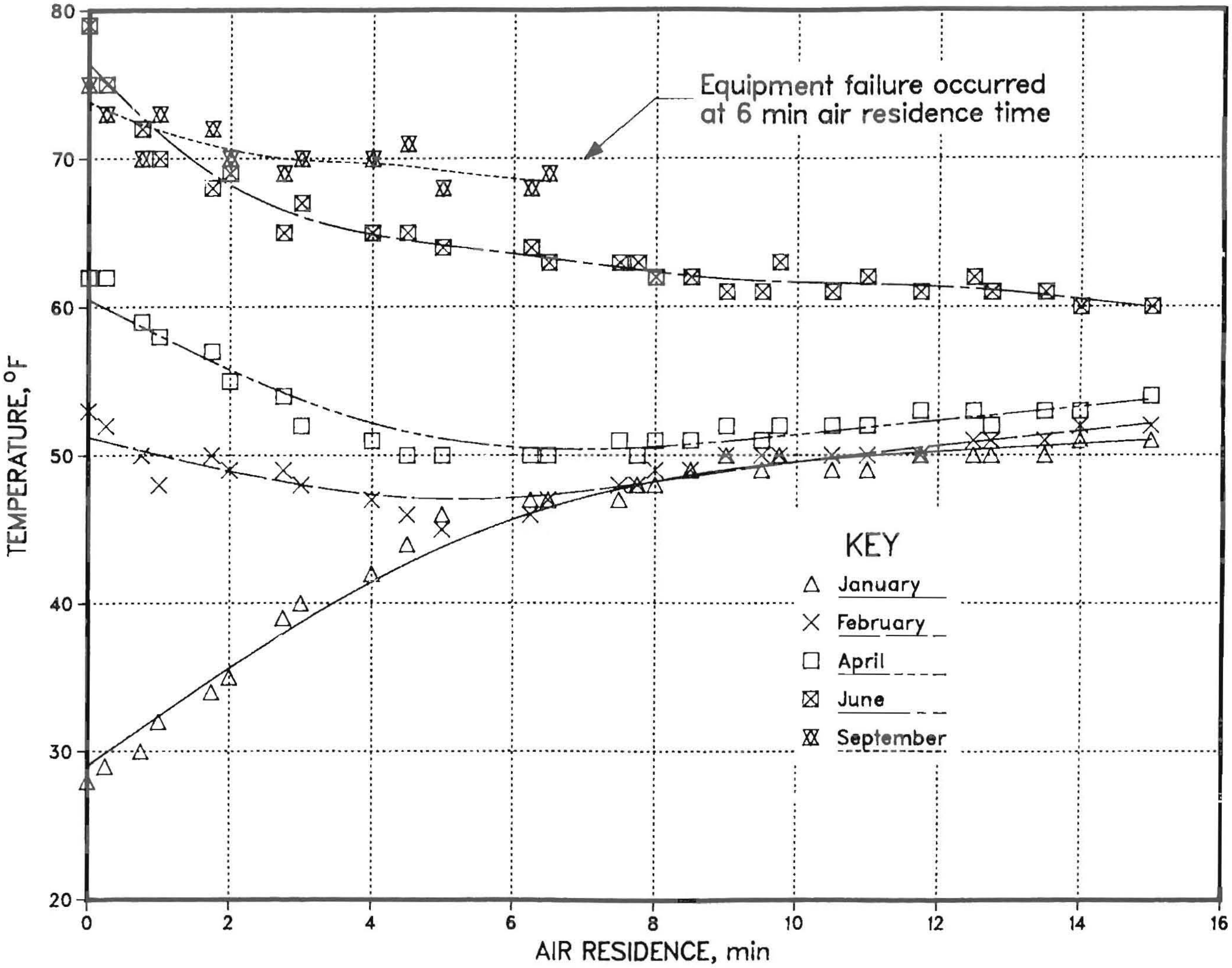

FIGURE 8. - Changes in mine air temperature as a function of air residence time.

gunite, and concrete blocks) form a large storage capacity for moisture, and they sometimes give striking evidence to the changes taking place in the mine atmosphere.

Posts can be seen loosening in winter to the point of falling down, and tightening, sometimes to failure, in summer. Rock dust in the entries forms a fine powder in winter, and in late summer can be compacted into tight balls by hand. Gunite and Mandoseal surfaces absorb little moisture, but the bounce back and overspray material on the floor is loose and granular in winter, and becomes hard and crusty in summer. The concrete blocks possibly display the least of the visual moisture effects. Still, they can be noticed to change from a uniform light gray color in winter to a dark gray in summer. All of these materials serve the tempering process in addition to maintaining the panel in good condition.

QUANTITATIVE DETERIORATION

Deterioration in 3 South is minimal. If an equal area of claystone roof was exposed to the same conditions, much worse deterioration after 4 or 5 yr would occur. This is evidenced in the 1 Right panel, which was abandoned after 7 yr. However, quantitative roof deterioration in 1 Right during its useful life demonstrated the need for modified design and roof support in future tempering panel development.

During midsummer, the roof and ribs were noticeably wet and the air foggy near the inlet of 1 Right. Roof deterioration was readily detected by frequent audible falls of small chunks of claystone and rapidly accummulating roof debris on the floor. On the outlet side of 1 Right the roof and ribs were dry, accumulated roof debris on the floor was less, and the frequency of audible roof falls was significantly less (7). Severe, progressive roof deterioration in the first half of 1 Right eventually forced total abandonment of the panel, including the relatively unaffected second half.

Quantitative evaluation of air tempering effectiveness in working areas is difficult and requires extended study. A control mine with similar roof conditions, without tempered intake air, is necessary for comparison. Reconnaissance observations in nearby mines under the same claystone roof with normal ventilation patterns do, however, support tempering effectiveness. The mines that expose their claystone roof to straight intake air typically experience constant minor roof falls and increasing pillar heights that severely affect rib stability. One nearby mine cut the claystone roof up to the overlying limestone and backfilled the entries with the claystone. This resulted in the floor of main intake and haulage entries being several feet above the top of the coalbed. The roof did stabilize (at great expense), but the claystone ribs continue to deteriorate.

Despite the difficulty in quantifying air tempering effectiveness in working areas, both management and workers at the No. 1 Mine agree that air tempering does yield tangible benefits. The consensus is that without air tempering upkeep and maintenance of haulageways and main intake airways, as well as maintenance of roof stability in working areas, would be difficult to economically unfeasible under the claystone roof. Personnel who are now working under claystone roof ventilated with tempered air, who have also worked under the same claystone ventilated by straight intake air, attest to tempering's effectiveness.

Bureau research in the No. 1 Mine and observations in similar nearby mines support the management and workers opinion. To this point, no severe deterioration like that experienced in 1 Right, or in nearby mines, has occurred inby 3 South.

TEMPERING ENTRY DESIGN

No firm design specifications are available for tempering entries, but certain design and mining guidelines can be offered as optimums. Guidelines for the location, mining, and compliance with ventilation and escapeway requirements for tempering systems are general. All can and probably should be modified for specific user needs.

LOCATION

The first consideration in tempering entry design is location. Tempering entries should be located as close to the intake shaft, slope, or drift, as possible. Close proximity to the shaft reduces support and maintenance expense in high velocity intake entries leading to the tempering panel.

If plans are being developed for an intake shaft and tempering entries, all available corehole data should be carefully examined for any resistant roof material. Locating tempering entries in moisture resistant roof rock can add years to the usable life expectancy of a tempering panel. The decreased deterioration that will occur under resistant roof rock also aids ventilation by reducing frictional resistance on intake air. As tempering entries in a moisture susceptable area deteriorate, the amount of power required by the fan(s) to overcome impeded passage in the airways continually increases.

The need for additional tempering panels to come on line as panels in use age and deteriorate should also be considered. If possible, sufficient coal reserves should be left near the shaft to accommodate several panels. As the useful life of a tempering panel is approached, the next panel layout can be mined, and easy transition into the new tempering entries can be achieved.

MINING

A conservative recovery percentage should be planned for tempering panels to insure roof stability. Although conservative recovery may increase initial cost, it is one of the easiest ways to decrease maintenance expense and increase life expectancy in tempering entries. Panels should be designed so that final configuration provides a minimum of 20- to 30-min air residence time with velocities of 300 fpm or less. Normal procedures for mining a standard production panel can be followed, with allowance for reduced recovery.

Tempering panels with straight-through airflow must be very wide and long to achieve desired residence times. By splitting the panel after mining, creating a looping ventilation pattern, air residence times can be greatly increased without a large increase in panel size. After mining, all the stoppings separating entries, except those near the center of the panel, are removed. This splits the panel in two. Air can then be directed down one side of the panel and back up the other.

The increased residence times achieved through looping ventilation are due to more efficient use of available panel space. The increased efficiency is gained by the elimination of dead air areas created in a straight-through ventilation pattern. In 3 South there are several dead air areas as well as unequal flow velocities across the panel width (as seen in figure 6). Velocities in the northeast and southwest corners of the panel sometimes drop below 10 fpm. Areas adjacent to increased panel width also experience severe velocity drops. In addition, air movement through the east half of the panel averages 50 to 75 fpm lower than the west half. Splitting 3 South, or any panel, would utilize the available area more efficiently. Splitting enables the intake airflow to expand and fill all the available space.

VENTILATION AND ESCAPEWAY REQUIREMENTS

Federal regulations state, in part, that "air that has passed through an abandoned area or an area which is inaccessible or unsafe for inspection shall not be used to ventilate any working place in any mine." Regulations also state, in part, that "at least two separate and distinct travelable passageways which are maintained to insure passage at all times of any person, including disabled persons, and which are designated as escapeways, at least one of which is intake air, shall be provided from each working section." The escapeways will be "located as to follow, as determined by an authorized representative of the Secretary, the safest direct practicable route to the nearest openings," and "all escapeways shall be examined in their entirety at least once each week" (16).

To comply with these regulations, tempering entries must be maintained in a safe condition if they provide the most direct route to the shaft. If a tempering panel is located in an area of resistant roof rock with straight-through ventilation, as 3 South in the No. 1 Mine, these regulations may pose no problems. If, however, the tempering panel entries can be expected to deteriorate, or a looping ventilation pattern is used, normal inspection of the airways and a long escapeway route may not be desirable or meet requirements. Under these condition continuous methane monitoring of air exiting the tempering panel may be required.

When considering the questions of tempering panel inspection and escapeway routes, close consultation with the responsible Mine Safety and Health Administration (MSHA) personnel is recommended. A petition to MSHA for variance in safety standards may be necessary. A paper by Lucas (13) describes a petition filed in Illinois to modify a required pre-shift examination of a tempering panel. The petition and the six resulting MSHA approval conditions are described in the paper. It may also be determined that the tempering entries are not the safest "direct practicable route to the nearest openings." In this case a fresh air split bypassing the tempering entries may be required as an escapeway. Air bypassing the tempering entries through a regulator can be remixed with tempered air at the panel outlet.

TEMPERING ENTRY SUPPORT

Tempering entry support, if designed and installed properly, can maximize the benefit of a tempering panel investment. An efficient roof support and sealant plan can greatly increase the life expectancy of a panel otherwise supported using a standard production roof support plan. In an air tempering panel the most useful types of support are bolts, sealants, and posts. These support systems can be combined to resist the effects of differing air residence times in the most efficient manner. However, in tempering entries mined under moisture sensitive shale, considerable deterioration should still be expected.

The roof support plan used in the 3 South panel at the No. 1 Mine, as previously described, is possibly the most efficient pattern available. The life expectancy of previous tempering panels using a standard production roof support plan was 7 to 8 yr. In 3 South, now in use for 5 yr, little or no signs of deterioration exist. Much of the success in controlling deterioration in 3 South is due to the good fortune of an available resistant roof rock (the hard black shale). However, the pattern of supports used is a good one, and only adjustments as to the amount of each type support (bolts, sealants, posts) to use in areas of deterioration prone shale are necessary. The following recommendations are for supporting a tempering panel under deteriorating shale roof conditions.

BOLTING

The type of bolts used in a tempering panel should depend on the area being supported. Mechanically anchored bolts are sufficient in areas to be sealed. Mechanical bolts should be anchored, if possible, in a competent unit above the moisture sensitive shale. This can prevent slippage and loss of bolt tension caused by deterioration at the anchorage horizon. Beyond the areas to be sealed, full column resin bolts are most effective. The resin surrounding the bolts seal the drilled hole, preventing circulation of mine air up into the roof. A laboratory test (2) of shale roof samples indicated that holes drilled into them significantly increased the amount of their moisture absorption. The greatest increase was in samples in which the holes are perpendicular to bedding, which is analogous to bolt holes drilled into the mine roof. The resin bolts used can be tensioned or nontensioned, so long as the hole is sealed from mine air circulation.

SEALANTS

Although sealants are expensive, their cost may be minimized and their effect maximized if they are properly applied in the most critical areas to be maintained. Areas in the first 5 min of air residence are exposed to the harshest conditions in the mine (figs. 7-8). In the first 5 min, air temperature rapidly moves toward ambient mine temperature, causing drastic changes in humidity. The next 5- to 10-min air residence also experiences severe changes in temperature and humidity, but not as forceful as those in the 0- to 5-min range.

Reinforcing wire mesh bolted to the roof and coated with two applications of gunite in the first 5 min of air residence is a very effective sealant that is itself resistant to deterioration. Gunite is a sand and cement mixture that is sprayed with a pressure gun onto the roof and ribs. A two-application coating of gunite will probably average 1 in. in thickness and will provide a very strong, impermeable seal in the entries. The

No. 1 Mine gunited only the first 1- to 3-min residence time areas. This included those portions of the entries where the hard black shale was removed, exposing the claystone. None of the gunited areas show signs of deterioration after 5 yr (fig. 9).

Areas in the next 5 to 10 min of air residence time should be protected with a single application of sealant after bolting. In the No. 1 Mine, areas in 2- to 4-min air residence are sealed with a 1/2-in flashcoat of Mandoseal. Although the claystone is not exposed in this area, the only signs of sealant deterioration are along the coal rib, where adherence is weak (fig. 10).

A generous amount of rock dust should be applied to the floor along the entire length of any sealed area. Because sealants do not absorb moisture, changes in intake air specific humidity in sealed areas mostly occur through condensation. Rock dust on the floor allows some moisture to be absorbed directly from the atmosphere, aiding the tempering action.

POSTING

Supplemental posts installed in the 3 South panel have been very effective because of the competent nature of the black shale roof (fig. 11). The only post maintenance required is tightening them against the roof in winter after they dry and shrink. Swelling in the summer forces the posts further and further into the floor, allowing them to loosen every winter.

The long-term utility of posts in a deterioration prone tempering panel may be questionable. However, their short-term utility (3-4 yr) may slow initial deterioration between bolts significantly. Treated posts and header boards can prevent sag and maintain the integrity of the roof between the regular bolting pattern. Any reasonable effort to slow the exposure of fresh roof by holding already exposed roof in place is worthwhile.

If supplemental posts are to be installed, they should be set at equal distances from the surrounding bolts wherever possible. The posts in 3 South were set in two rows on 5-ft centers in the entries and in one row on 5-ft centers in the crosscuts. This pattern does not center posts. However, other patterns that do, using the same number or less posts, can be arranged (fig. 12). Considering costs in a 30-min tempering panel, posts installed in the 10- to 20-min residence areas would probably be the most cost effective plan. At the 20-min point, the rate of shale deterioration should be greatly reduced, reducing the need for any supplemental posting.

CONCLUSIONS AND RECOMMENDATIONS

Air tempering entries are an effective method of controlling deterioration prone shales in coal mines. Bureau research indicates that with proper planning and support the usable life expectancy of a tempering panel can be greatly extended. The need to control shale roof deterioration during the mining process is evident. Mines operating under severely deteriorating shale roofs are often forced to work with ever increasing pillar heights because of constant falls of roof. This action results in constant floor obstructions, increased frictional resistance to airflow, weakening of the rib line because of increased pillar height, and increased maintenance costs in the main haulage roads and airways.

The conclusions drawn from this study are as follows:

1. When changing weather systems affect the average specific humidity of an area, or changing seasons affect overall average specific humidity, moisture sensitive shales exposed to those changes can be expected to react adversely to moisture gains and losses.
2. Although intake air specific humidity fluctuations sometimes do occur beyond the tempering entries, the majority effects of both the short-term high- and low-specific-humidity variations, and the seasonal differences in average specific humidity, are concentrated in and absorbed by the tempering entries.

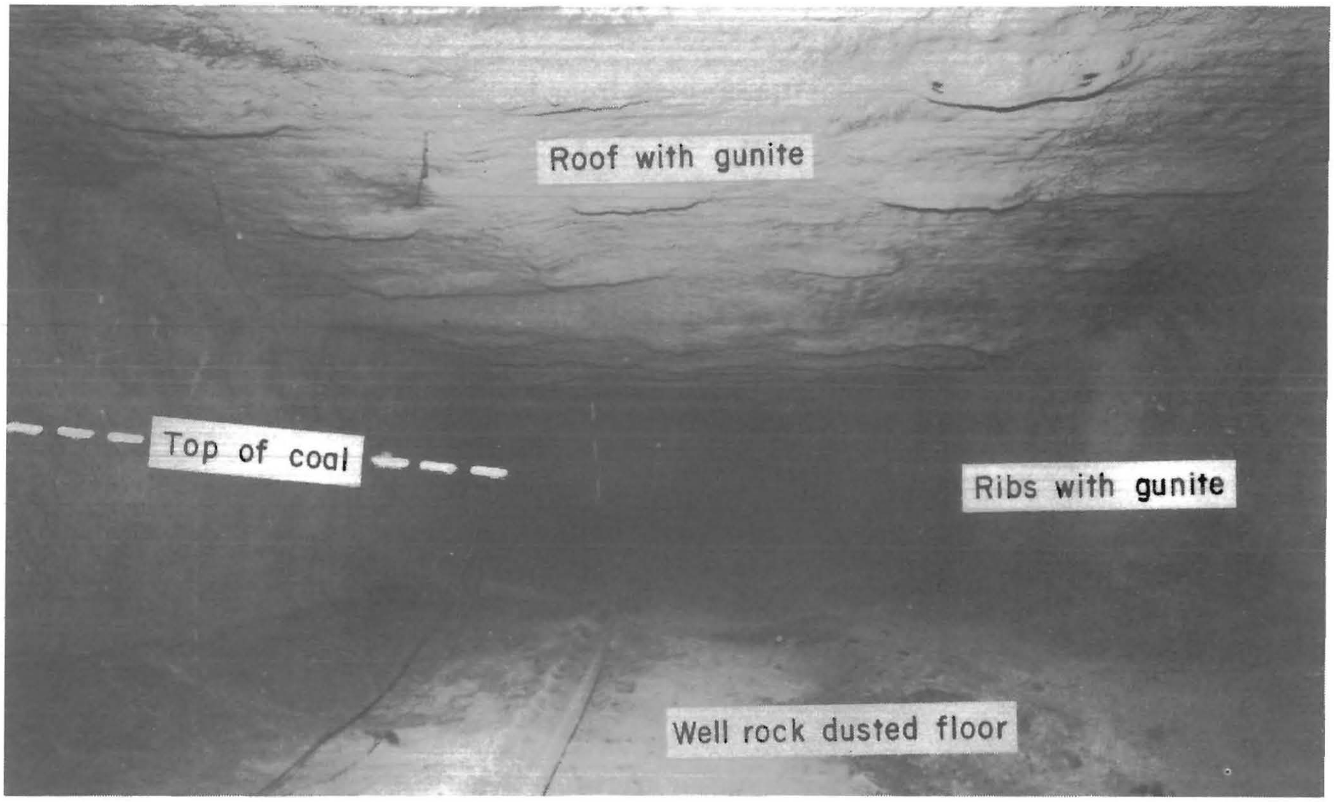

FIGURE 9. - Area of 3 South under exposed claystone roof sealed with gunite.

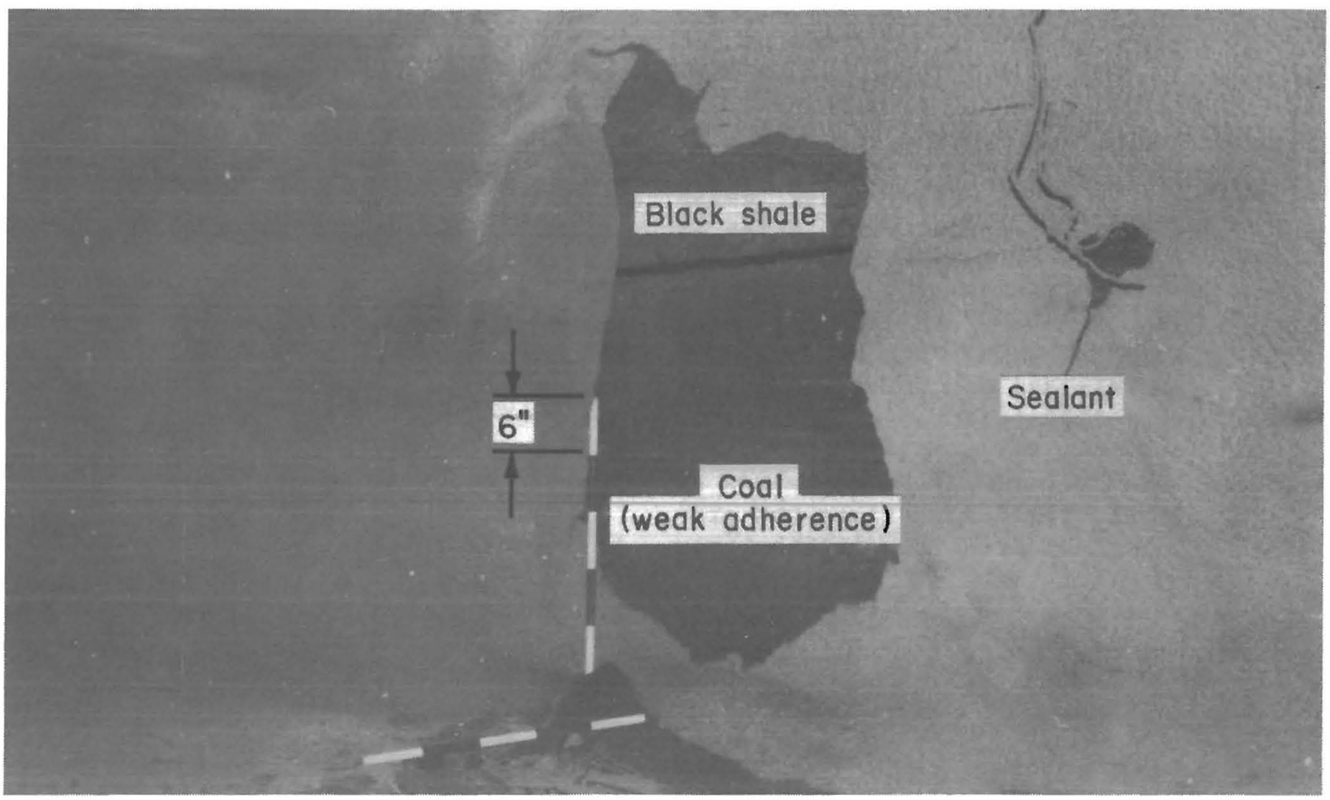

FIGURE 10. - Area of 3 South under black shale roof sealed with Mandoseal, illustrating some spalling effects along the coal rib.

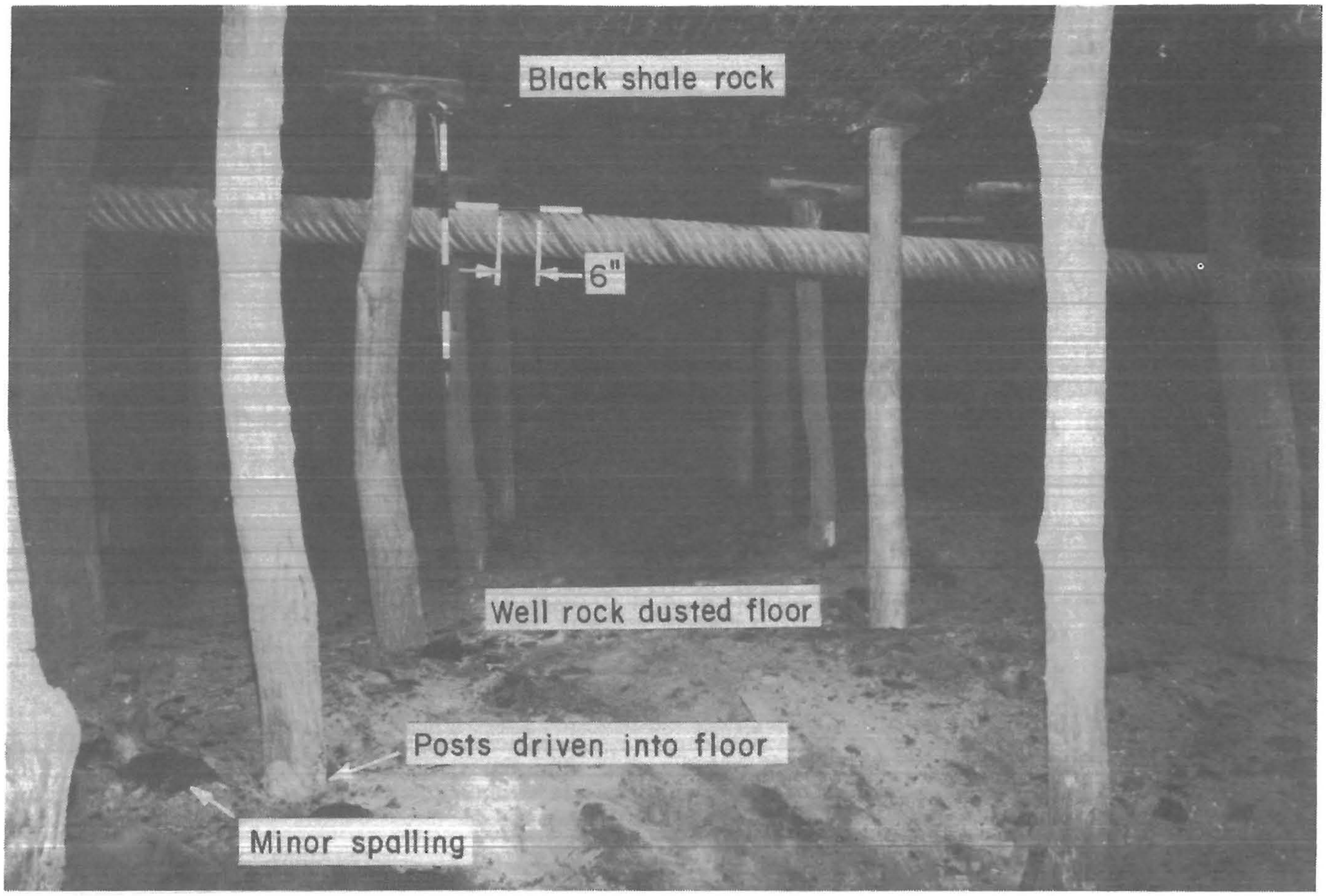

FIGURE 11. - Typical posted intersection in 3 South beyond sealed areas.

3. The quantitative evaluation of tempering effectiveness in reducing shale roof deterioration in working areas is difficult. However, consensus at the No. 1 Mine is that air tempering is both effective and necessary in reducing roof spalling and falls in main haulage and airways, as well as active mining areas, under their claystone roof. Bureau research supports this opinion. Graphic evidence that deterioration decreases at increasing air residence times was provided by past observation in the now abandoned 1 Right tempering panel.

4. Certain tempering entry panel design and mining guidelines can be offered as optimums.

A. Tempering panels should be located as near to the main intake as possible. Position the main intake and tempering panel areas in any available resistant roof material if it is feasible during early mine design or expansion development. Panels located in areas of moisture sensitive shale roof should be expected to experience considerable deterioration.

B. Tempering panels should be designed for a conservative recovery with a final configuration that will provide a minimum 20- to 30-min air residence time. Air residence times can be increased without increasing panel size with a looping ventilation pattern.

C. Ventilation and escapeway requirements must be given careful consideration early in panel design. Close consultation with the responsible MSHA personnel concerning those requirements is recommended.

5. Bolts, sealants, and posts can be combined to effectively resist roof spalling and falls caused by specific humidity fluctuations in the tempering entries. Sealants, in addition to roof bolts, should be applied in the panel

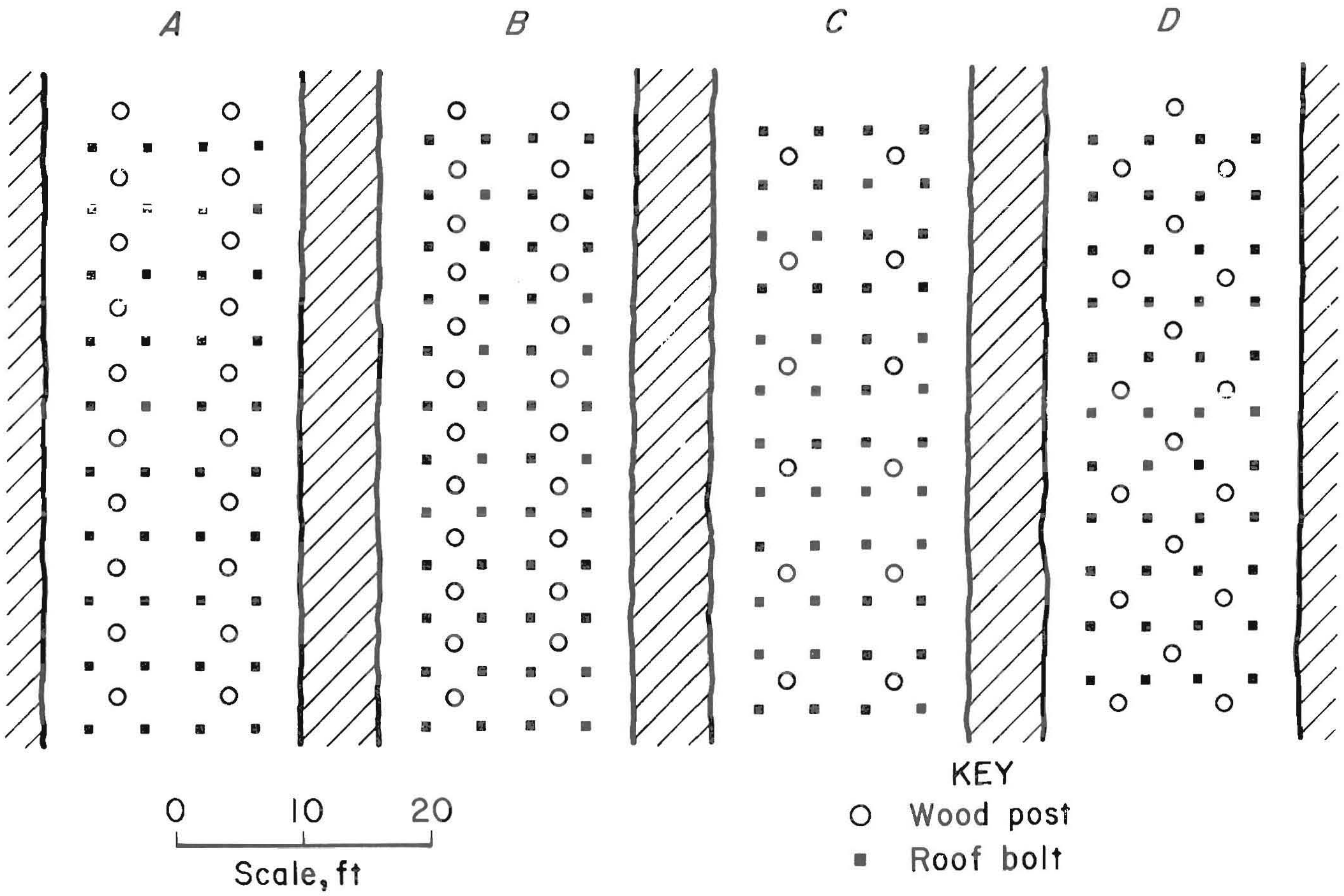

FIGURE 12. - Possible posting patterns to center posts between existing bolting patterns.

area exposed to the first 10 min of air residence time to resist the harshest atmospheric conditions in the tempering panel. Mechanically anchored bolts are sufficient in sealed areas, but full column resin bolts are desirable elsewhere. Posting unsealed portions of a tempering panel adds to roof stability as well as forming a large storage capacity for moisture.

REFERENCES

1. Aughenbaugh, N. B., and R. F. Bruzewski. Investigation of the Failures of Roofs in Coal Mines (contract H0111462, Univ. MO--Rolla). BuMines OFR 55-75, 1973, 135 pp.; NTIS PB 243 375.

2. ______. Humidity Effects on Coal Mine Roof Stability (contract H0232057, Univ. MO--Rolla). BuMines OFR 5-78, 1976, 164 pp.; NTIS PB 276 484.

3. Bruzewski, R. G., and N. B. Aughenbaugh. Effects of Weather on Mine Air. Min. Congr. J., Sept. 1977, pp. 23-27.

4. Cummings, R. A., M. M. Singh, and N. N. Moebs. Effect of Atmospheric Moisture in the Deterioration of Roof Shales. Min. Eng. (N.Y.), Mar. 1983, pp. 243-245.

5. Haynes, C. D. Effects of Temperature and Humidity Variations on the Stability of Coal Mine Roof Rocks Final report (contract H0122111, Univ. AL). BuMines OFR 8-77, 1975, 385 pp.; NTIS PB 262 516.

6. Stateham, R. M., and D. E. Radcliffe. Humidity: A Cyclic Effect in Coal Mine Roof Stability. BuMines RI 8291, 1978, 19 pp.

7. Cummings, R. A., M. M. Singh, S. E. Sharp, and A. W. Laurito. Control of Shale Roof Deterioration With Air Tempering. Volume I--Field and Laboratory Investigations (contract J0188028, Eng. Int., Inc.). BuMines OFR 41(1)-82, 1981, 164 pp.; NTIS PB 82-199985.

8. Artler, L. Coal Mine Sealants. Min. Congr. J., Dec. 1974, pp. 34-39.

9. Brown, G. M. Keep Damp Roof Rock From Spalling by Spraying With Coal-Tar Paint. Coal Age, v. 46, No. 5, 1941, pp. 64-65.

10. Franklin, J. C., K. D. Weverstad, and R. F. Marquardt. Polymeric Sealant Used To Stop Shale Degradation in Coal Mines. BuMines TPR 103, 1977, 8 pp.

11. Conrad, H. G. Air Conditioning. Min. Congr. J., June 1936, pp. 31-33.

12. Fish, E. L., L. A. Turnbull, and A. L. Toenges. A Study of Summer Air Conditioning With Water Sprays To Prevent Roof Falls at the Beech Bottom Coal Mine, West Virginia. BuMines RI 3775, 1944, 20 pp.

13. Lucas, W. S. Tempering Mine Air To Prevent Roof Falls. Paper in Proceedings 83d Annual Meeting, Illinois Institute (Springfield, IL, Oct. 2-3, 1975), pp. 47-55.

14. Hartman, I., and H. P. Greenwald. Effects of Changes in Moisture and Temperature on Mine Roof. 1. Report on Strata Overlying the Pittsburgh Coal Bed. BuMines RI 3588, 1941, 40 pp.

15. McNary, H. B. Investigation of Mine Roof Disintegration. Min. Congr. J., v. 27, No. 4, 1941, pp. 28-30.

16. U.S. Code of Federal Regulations. Title 30--Mineral Resources; Chapter I--Mine Health and Safety Administration, Department of Labor; Subchapter O--Coal Mine Safety and Health; Part 75--Mandatory Safety Standards--Underground Coal Mines; Subpart D--Ventilation, sec. 75.312, and Subpart R--Miscellaneous, sec. 75.1704 and sec. 75.1704-2; July 1, 1982.

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